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Dundalk Sewershed Evaluation Study Plan
Project No. 1047
RJN Job No. 17-2252

Model Development and Calibration Report

Sanitary Sewer Overflow Consent Decree
Civil Action No. JFM-02-1524

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1.0 INTRODUCTION

1.1 Sewershed Description

The Dundalk sewershed, shown in **Figure 1-1**, is generally bounded by Eastern Avenue to the north, Inner Harbor to the south, Baltimore City/Baltimore County line (Central Avenue) to the east, and Newkirk Avenue to the west. Interstate 95 runs along the northwest border of the sewershed.

The Dundalk sewershed is about 2500 acres in size with approximately 153,000 lf of pipe ranging in diameter from 8-inch to 66-inch, 600 manholes and one pump station. The covered area is generally a combination of residential and commercial property with a heavy industrial component. Wastewater from the Dundalk Sewershed discharges to the Outfall Sewershed at one location before being treated at the City's Back River Wastewater Treatment Facility.

1.2 Objectives

This report mainly describes the development and calibration of the hydraulic model established for the Dundalk sewershed. This report also describes engineering tasks that have been performed on the Dundalk sewershed and are critical to model development, including flow monitoring, manhole inspection, and GPS survey.

1.3 Flow Monitoring Program

Based on extensive sewer system evaluation study (SSES) and requirements of the Consent Decree, the City reviewed the Dundalk sewershed and divided the sewershed into seven sub-basins. Under the City's Project 995, flow meters and rain gauges were installed for Dundalk and data was collected for approximately a one year period from May 2006 to May 2007. The seven sub-basins within the City boundaries and corresponding flow meters are named as DU01, DU02, DU03, DU04, DU05, DU06, and DU07. In addition, a flow meter TSDU03 was installed just upstream of the outfall to monitor the total flows discharged from the Dundalk sewershed to the Outfall sewershed.

The Dundalk sewershed also receives flow from Baltimore County in several locations. Flow meters were installed at four major points of connection to capture flow data from the largest basins in the County's Dundalk sewershed. These basins and corresponding flow meters are named as BDU01, BDU02, BDU03 and BDU04. Meters for BDU01 and BDU02 were installed as part of the City's Project 995, and BDU03 and BDU04 were installed in March 2008. A flow meter schematic with flow balance for Dundalk Sewershed is shown in **Figure 1-2**. The location of these flow meters, their installation history, and uptime are presented in **Table 1**.

Upon installation and activation of each flow meter, the flow monitoring Contractors took manual depth and velocity readings using an independent instrumentation to confirm that the in-situ monitor yielded data representative of actual field conditions. The field crews were required to take manual velocity readings of the cross-section (velocity profile) of the flow in order to determine the pipe hydraulic profile. RJN further reviewed the collected meter data to ensure accuracy.

To measure the rainfall, a network of 20 rain gauges was installed with a minimum coverage of one (1) rain gauge per ten (10) square miles. In addition to the 20 rain gauges, the City performed Doppler Radar Rainfall Analysis with a resolution of one (1) pixel per one (1) square kilometer as required by the Consent Decree. A composite rain trace derived from all rain gauges (**See Section 5.2.3**) was utilized in conjunction with Doppler radar data for modeling purpose.

Table 1
Dundalk Model Calibration Report: Introduction
Flow Meter Summary

Meter	Sub-basin	Manhole ID	Installation History		% Uptime
			Installation Date	Removal Date	
DU01	DU01	S65A1__005MH	Friday, March 31, 2006	March-07	99.2%
DU02	DU02	S59W__004MH	Thursday, January 19, 2006	March-07	90.6%
DU03	DU03	S63M__010MH	Tuesday, March 07, 2006	March-07	98.3%
DU04	DU04	S67Y__006MH	Thursday, April 06, 2006	March-07	93.0%
DU05	DU05	S69C1__008MH	Monday, January 09, 2006	March-07	99.2%
DU06	DU06	S71Y__008MH	Monday, January 09, 2006	March-07	99.7%
DU07	DU07	S69Q__011MH	Wednesday, January 18, 2006	March-07	95.2%
BDU01	BDU01	S71S__005MH	Wednesday, January 18, 2006	Permanent	95.4%
BDU02	BDU02	S71O__003MH	Wednesday, January 18, 2006	Permanent	91.8%
BDU03*	BDU03	TCM151	Friday, February 29, 2008	Permanent	88.0%
BDU04*	BDU04	901004	Friday, February 29, 2008	Permanent	97.0%
TSDU03	-------	S65A__011MH	Wednesday, May 17, 2006	Permanent	96.7%

* Meters BDU03 and BDU04 are within Baltimore County boundaries.

1.4 Field Investigations

1.4.1 Manhole Inspection

RJN performed manhole inspections to evaluate manhole condition, identify potential source of inflow/infiltration, verify flow direction/pipe connectivity, and also provide data for hydraulic model development. The data includes pipe shape, pipe size, depth from manhole rim to each pipe invert, and silt level. A total of 139 manholes out of 235 modeled manholes were inspected prior to the development and calibration of the hydraulic model. Those manholes not inspected were due to various reasons, such as manhole buried, manhole belonging to private utilities, manhole unable to open, or unable to access because of heavy traffic.

1.4.2 GPS Survey

A GPS survey was conducted to obtain horizontal and vertical datums of manholes in Dundalk. The collected X-Y coordinate data of each manhole was verified against GIS information provided by the City to ensure accuracy of manhole locations. A total of 175 manholes out of 235 modeled manholes were GPS surveyed. Rim elevation (Z coordinate) was collected using conventional methods and RTK GPS with sub-centimeter accuracy. Invert elevations were determined by "measure downs" conducted during the manhole inspection process for input into the hydraulic model.

2.0 PHYSICAL MODEL DEVELOPMENT

The modeled sewer network is defined as all gravity sewer lines 10-inch in diameter or greater. In addition, the following sewer lines were also included in the network:

(a) Gravity sewer lines that may contribute to capacity related overflows; e.g., 8-inch lines through Ft. Holabird Park in basin DU05

(b) Force mains that convey wastewater from the Dundalk pump station to gravity lines

The modeling software package selected for the City of Baltimore's collection system is InfoWorks CS developed by the Wallingford Software, Inc. The initial model of the Dundalk sewershed was developed based on the GIS information provided by the City. ESRI ArcView shape files for nodes (e.g., manholes), links (e.g., conduits), and sub-catchments were readily imported into InfoWorks CS and data (e.g., horizontal coordinates and conduit size) was then extracted to populate the model. The initial network generated includes all manholes and conduits in Dundalk, and sewers and manholes deemed not to be included in the model were subsequently removed.

Node data processed at this stage includes node type, horizontal datums and flood type. A node can be defined as any of the five different types in InfoWorks CS and they are break, manhole, outfall, pond, and storage. 248 nodes are defined as "manhole" in the model which also include the wet well at the Dundalk pump station and 12 dummy manholes (representing a junction chamber and connections along gravity lines where pipe size or gradient changes). The node on East Lombard Street where sewerage discharges from the Dundalk area is defined as "outfall". Ten (10) nodes in the model are defined as "break", no storage capacity and used on pressure pipes only to represent a change in gradient. A review of the City's horizontal datum for manholes was conducted and the data matches well with the GPS data collected by RJN. The City shape file did not include elevation data (Z coordinate); the information was derived from GPS data and record drawings (**See Section 3.1**). Flood type for all real manholes is set to "lost" and it means that flood water is lost from the system once the water level in a manhole reaches rim elevation. Flood type for dummy manholes is set to "sealed".

Link data processed at this stage includes link type, connection (upstream and downstream nodes), and conduit shape and size (if defined as conduit). A link can be defined as any of the nine hydraulic structures in InfoWorks CS, including conduit, weir, pump, orifice, valve, flume, screen, siphon, and sluice. Links in the model are all represented as conduits except 4 pumps (represented as a link of zero length in InfoWorks CS) at the Dundalk pump station. Conduit connections were verified by field data collected during manhole inspection process, and wrong connections and flow directions were updated correspondingly. A majority of conduits in Dundalk are circular though sewers in other shapes do exist. For example, a section of semi-elliptical sewer begins at a transition node (approximately 550 ft north of manhole S67M__003MH on O'Donnell Street) on the major gravity interceptor and ends at the outfall. All pipe sizes were checked prior to model calibration and further modeling efforts.

The City further divided the 7 meter basins in Dundalk into 33 sewershed service areas (SSAs). In accordance with the BaSES manual, RJN further divided these sewershed service areas into smaller drainage areas (i.e., sub-catchment in modeling terminology) tributary to the flow monitoring locations. The delineation of SSAs into sub-catchments was manually performed on the map according to the location of sewers, flow directions, and parcel boundaries. These delineated sub-catchments were subsequently digitized and loaded into InfoWorks CS. Delineated sub-catchments are primarily 10 - 40 acres in size. Larger sub-catchments also exist in Dundalk sewershed; for example, the marine terminal in basin DU05 where sewer lines run along the northern boundaries of the sub-catchment. Four basins were created to represent main County contributions: BDU01, BDU02, BDU03, and BDU04, and no further delineation of these basins into smaller sub-catchments were attempted as manholes and sewers within the County boundaries were not included in the model. As a result, a total of 95 sub-catchments were created for Dundalk. The naming of sub-catchments matches that of corresponding SSAs when SSAs are not sub-divided. Otherwise, sub-catchments in the same SSA will have an identical name except the last one-character suffix (i.e., 29-02-13-00A and 29-02-13-00B).

Sub-catchment data processed at this stage are total area and contributing area. The total area of a sub-catchment was calculated automatically by the software. Further adjustment to the contributing area was made to account for parcels (e.g., cemetery and park) that are not connected to the collection system.

3.0 MODEL DATA INPUT

3.1 Node Data Input

As described in the previous section, node type, horizontal coordinates, and flood type have been entered into the physical model for each node. Additional parameters required to define a manhole include Z coordinate, chamber roof and chamber floor elevations, and chamber and shaft areas. The Z coordinate of each manhole is termed as "ground level" in InfoWorks CS and it was derived from field-collected GPS source data. In cases where a GPS coordinate could not be obtained in the field, record drawings were used to obtain the information. Prior to using an as-built based elevation for a manhole that was not GPS surveyed, as-built based elevations for surrounding manholes were compared to GPS based elevations to ensure accuracy of the GPS data. In most cases, GPS data collected compares favorably with record drawings. Consequently, 49 manholes have record drawing based rim elevations. In the absence of both GPS coordinates and record drawings, rim elevations for 11 manholes were inferred by the software. All nodes defined as "break" have record drawing based elevations.

Manhole chamber floor and chamber roof levels were calculated by the software using the minimum and maximum of all invert levels of pipes connecting a manhole, respectively. Chamber and shaft areas were calculated by software using the equation below:

$$A = \frac{\pi}{4} \times (W + 0.762)^2$$

Where A is the shaft or chamber area and W is the width of the widest pipe connecting a manhole. The chamber and shaft areas of dummy manholes were set to a small value of 0.2 ft^2. The depth, chamber area, and shaft area of the wet well at the pump station were derived from pump station drawing plans.

3.2 Link Data Input

Additional link data required for modeling includes solution model, pipe roughness type, top and bottom roughness coefficients, head loss coefficients, pipe invert values, and pump operation conditions. The "full" solution model applies to all gravity lines and the "ForceMain" solution model applies to the force mains. Manning's roughness (*n*) is set to a standard value of 0.013 for all conduits initially and tuned while model calibration. Headloss represents energy loss at transitions between a manhole and the connecting conduits due to flow turbulence as well as energy loss at bends where flow direction changes. Headloss type is set to "normal" assuming all manholes were properly constructed. Further, upstream and downstream headloss coefficients of all conduits were inferred by the model to account for change in flow direction; for example, a headloss coefficient value of 6.6 will be applied to a 90^o bend. Pipe inverts were developed in a spreadsheet based on rim elevations (GPS data) and "measure downs" (depth from rim elevation to each pipe invert), and calculated values were then imported into InfoWorks CS. In cases where a manhole could not be inspected, inverts were derived from record drawings. Inverts were not read directly from record drawings; rather missing inverts were back-calculated using as-built based pipe gradients and GPS based inverts at the downstream or upstream ends of these conduits. Nodes defined as "break" have as-built based inverts for connected pipes. Finally, 12 conduits in the model have inferred inverts since neither GPS nor as-built based information is available.

Four variable frequency drive pumps are used at the Dundalk pump station to convey wastewater through a 36-inch force main to a 54-inch gravity line. The design capacity of the pump station is 33 MGD when three pumps operate in parallel at a nominal speed of 710 rpm (23,100 GPM @ 112' TDH). A pump curve (at the nominal speed) was obtained and a head-discharge table was created for each pump in InfoWorks CS. Further, a pump operating speed range, acceleration and deceleration rates were obtained and input into the model. In addition, a pump operating guide was obtained from the City for the Dundalk Pump Station which provided input into InfoWorks of the on and off levels for each pump. Note, the on and off levels for the 4th pump (backup pump) are not available and the 4th pump will be turned on whenever required, depending on the magnitude of a storm event. For the purpose of this study, the on and off levels for the 4th pumps are set to the "high level alarm" level and the switch-on level of the 3rd pump, respectively. Lastly, a real time control scenario was created in InfoWorks where a proportional–integral–derivative (PID) controller was adopted to maintain a water level of 5 feet in the wet well.

3.3 Sub-Catchment Data Input

Additional parameters were specified for each sub-catchment, including loading point, population, land use, and runoff surface. Loading point is the manhole to which a sub-catchment drains. As only one loading point can be specified for each sub-catchment in InfoWorks CS, the last manhole on the reach of a sub-catchment was designated as the loading point to avoid dry conduits. Population data for each sub-catchment was obtained through GIS intersection with the U.S. Census Block data. A unique land use was assigned to each meter basin (**Table 2**), and all sub-catchments inside a meter basin therefore have the same land use. Each sub-catchment is represented by three types of runoff surfaces: road, roof, and pervious area (e.g., lawn), and they represent paths that storm water can potentially take to enter the sanitary sewer collection system. The percentage of contributing areas such as road, roof, or pervious area was estimated and input into the model.

Table 2
Dundalk Model Calibration Report: Model Data Input
Summary of Land Use, Waste Water, Trade Waste, and Rainfall Profiles

Sub-Basin	Land Use ID	Waste Water ID	Trade Waste ID	Rainfall ID
DU01	1	1	1	1
DU02	2	2	2	2
DU03	3	3	3	3
DU04	4	4	4	4
DU05	5	5	5	5
DU06	6	6	6	6
DU07	7	7	7	7
BDU01	8	8	8	8
BDU02	9	9	9	9
BDU03*	10	10	10	5
BDU04*	11	11	11	5

* For BDU03 and BDU04, Geographic information (i.e., the distance from the centroid of a meter basin to each rain gauge) and Doppler radar rainfall were not loaded into Sliicer. The rainfall profile of DU05 is applied to BDU03 and BDU04 for calibrations of flow and depth at meter site DU05 during all 29 storm events from May 2006 to April 2007.

3.4 Data Flags

Data flags are a powerful tool in InfoWorks CS, which allow users to indicate source and integrity of the data in the model. Each flag has a two-character ID with a designated color. Besides standard data flags already defined in InfoWorks CS, RJN added additional data flags to represent data coming from various sources, such as GPS survey or inferred by the model. **Table 3** summarized the data flags used in the model.

Table 3
Dundalk Model Calibration Report: Model Data Input
Data Flags

ID	Description	Display Color
#A	Asset Data	
#D	System Default	
#G	Data from GeoPlan	
#I	Model Import	
#V	CSV Import	
AD	Assigned by modeler/Calibrated Parameter	
GI	GIS Data	
GP	GPS/Field Data/Sliicer Analysis	
IF	Inferred Data	
RD	Record Information	

4.0 MODEL VALIDATION

Before calibration and further modeling efforts can be performed, the hydraulic model has to be validated. A standard validation was conducted to check for missing values (e.g., missing rim elevations) and errors (e.g., isolated nodes) of the network. Further engineering validation was performed to check if any network data is inconsistent with engineering expectations, including

- Extremely short or long conduit length
- Negative pipe gradients, flat or extremely steep pipe gradients
- Nodes with more than one outgoing pipe
- Node drop (maximum allowable step down in invert levels across manhole)
- Pump station not adjacent to break nodes

Engineering validation generates warning messages for inconsistencies found in the model. These messages do not necessarily mean the network data is wrong, rather they suggest that data is questionable and requires verification. An example of these is that engineering validation indicated sewers with negative pipe gradients. A further review of this confirmed that it was true and it occurred along the Dundalk force main.

5.0 MODEL CALIBRATION AND VERIFICATION

The City's Project 995 – Citywide Flow Monitoring Program has provided RJN with over a year's worth of rainfall and flow data in Dundalk. The data was used for dry weather and wet weather calibrations of the Dundalk hydraulic model. The following paragraphs of this section describe the steps of the calibration and how parameters were derived and manipulated to make modeled response match observed data.

5.1 Dry Weather Calibration

5.1.1 Sliicer Application (Dry Weather Analysis)

ADS's program Sliicer was used in this project to perform wastewater and base infiltration analyses during dry weather and inflow/infiltration analysis during wet weather. **Table 4** provides criteria for a day to be designated as a dry day, according to the BaSES manual.

Table 4
Dundalk Model Calibration Report: Model Calibration and Verification
Criteria for Dry Days

Number of Prior Days	Cumulative Antecedent Rain (Inches)
1	0.1
3	0.4
5	1

In addition, dry days with unusual flow patterns or dry days with total flows that were 15% higher or lower than the average volume of all dry days were excluded from the analysis. Therefore, average dry weather flow for each meter basin was created and this was subsequently used to calculate wastewater and base infiltration components.

According to a City memorandum issued on June 20, 2008 (RFI-34: Base Sanitary Flow Formula, BaSES 7.4.5), the Stevens-Schutzbach method was adopted to calculate wastewater and base infiltration components.

$$BaseInfiltration = \frac{0.4 \times MDF}{\left(1 - \left(0.6 \times \left(MDF/ADF\right)^{(MDF)^{0.7}}\right)\right)}$$

Where MDF denotes minimum dry flow (usually occurring between 2 and 4 am in the morning), and ADF denotes the average dry flow. The total wastewater was then calculated by subtracting the base infiltration (BI) from the average dry flow (ADF).

5.1.2 Wastewater

As discussed in **Section 1.1**, the Dundalk sewershed is a combination of residential and commercial property with a heavy industrial component. The generated wastewater includes sanitary flow as well as industrial and commercial flow. InfoWorks CS inputs sanitary flow based on population, diurnal variation, and per capita wastewater generation rates. Industrial and commercial flow can be represented as "Additional foul flow".

The City has provided RJN a shape file for Top 100 Water Users in Dundalk. A return factor of 0.75 was applied to the water consumption data to account for flows that were not returned to the collection system. A review of NPDES (National Pollutant Discharge Elimination System) permits for wastewater discharge from several largest water users in Dundalk suggests that the return factor of 0.75 is reasonable. Adjusted industrial and commercial wastewater flows were then input into the model as "Additional foul flow" for each sub-catchment (if industry or commercial property falls within a sub-catchment). The wastewater hourly diurnal peaking factors (see below) are applied to the "Additional foul flow" as well.

The total industrial and commercial flow of each of the 7 meter basins (BDU01, BDU02, BDU03, and BDU04 within the County boundaries are mainly residential areas with small industrial and commercial flow) was subtracted from average dry weather flow to calculate residential sanitary flow. The residential sanitary flow was then divided by population to calculate the per capita wastewater generation rate for each meter basin. Finally, a Wastewater Group (WWG) was created and a unique wastewater profile was assigned to each of the 11 meter basins with weekday and weekend hourly diurnal peaking factors (derived from weekday and weekend average dry weather flow patterns) and a per capita wastewater generation rate was specified. Sub-catchments within a meter basin have the same wastewater profile. The wastewater profile ID for each meter basin is presented in Table 2.

5.1.3 Base Infiltration

Base Infiltration represents flow entering a collection system due to groundwater infiltration when groundwater levels are not impacted by rain. Based on the Stevens-Schutzbach equation, average annual base infiltration was calculated for each meter basin. The base infiltration of each sub-catchment within a meter basin was distributed proportionally based on contributing area. Calculated base infiltration was then input into the model as "Trade flow".

Base infiltration can be a constant inflow; nevertheless, varying base infiltration can generally be expected due to seasonal variation of groundwater level. Therefore, base infiltration monthly factors were calculated based on one (1) year of flow data from May 2006 to May 2007 and input into the hydraulic model as "Trade Waste" profiles. Sub-catchments within a meter basin have the same trade waste profile. The trade waste profile ID for each meter basin is presented in Table 2.

5.1.4 Dry Weather Calibration Criteria

Modeled and observed data will be plotted in time series comparing flow for each meter site. The following criteria will be used to perform dry weather calibration:

- The modeled peak flow rate should be within -10 to +20 percent of observed peak flow rate
- The model volume should be within -10 to +20 percent of observed volume
- The timing of peaks should be within 1 hour

5.1.5 Calibration Results

The feature "Observed & Predicted Reports" in InfoWorks CS offers a way to compare modeled data to observed data in time series. Prior to such a comparison, a Flow Survey Group (FSG) was created where dry weather flow survey data was saved.

Dry weather calibration was first performed for a 2-day period (Friday and Saturday) so that modeled response can be checked for weekdays and weekends. Notably, modeled response was compared to average dry weather flows during summer 2006 with the exception of meter basins BDU03 and BDU04. Meters BDU03 and BDU04 were installed in March 2008 and modeled response for these basins is compared to average dry weather flow in a period from March 14 2008 to June 30 2008. Modeled and observed data are summarized in **Table 5** and time series plots of flow are provided in **Appendix A**. The dates in the plots are not relevant, but rather input to illustrate the comparison of modeled versus observed response. As it can be seen from the table and time series plots, the shapes of the modeled hydrographs match those of observed hydrographs, and modeled peak flow rate and volume compare favorably with observed data. Modeled flows were further compared to metered flows during a dry winter week February 05, 2007 through February 12, 2007 when base infiltration was elevated due to higher groundwater level. The modeled hydrographs match satisfactorily with observed hydrographs and time series plots of flows are provided in Appendix A.

Table 5
Dundalk Model Calibration Report: Model Calibration and Verification
Dry Weather Flow Calibration Statistics

Meter	Minimum Flow (MGD)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
	Obs	Sim	Error%	Obs	Sim	Error%	If Match	Obs	Sim	Error%	
DU01	0.480	0.513	6.9%	0.957	0.887	-7.3%	Yes	1.464	1.471	0.5%	
DU02	0.516	0.498	-3.5%	0.802	0.805	0.4%	Yes	1.371	1.375	0.3%	
DU03	0.429	0.431	0.5%	0.695	0.696	0.1%	Yes	1.194	1.199	0.4%	
DU04	0.154	0.162	5.2%	0.306	0.308	0.7%	Yes	0.465	0.477	2.6%	
DU05	2.237	2.311	3.3%	4.281	4.557	6.4%	Yes	6.774	7.112	5.0%	
DU06	0.715	0.747	4.5%	1.487	1.483	-0.3%	Yes	2.314	2.311	-0.1%	
DU07	0.266	0.290	9.0%	0.678	0.657	-3.1%	Yes	0.921	0.933	1.3%	
BDU01	0.173	0.174	0.6%	0.338	0.335	-0.9%	Yes	0.521	0.520	-0.2%	
BDU02	0.084	0.094	11.9%	0.216	0.234	8.3%	Yes	0.305	0.334	9.5%	
BDU03	0.616	0.616	0.0%	0.973	0.971	-0.2%	Yes	1.655	1.654	-0.1%	
BDU04	0.838	0.863	3.0%	1.523	1.499	-1.6%	Yes	2.204	2.204	0.0%	
TSDU03	2.388	2.788	16.8%	5.020	6.011	19.7%	30 minutes	8.004	9.380	17.2%	Observed TSDU03 volume less than the total volume of DU01, DU04, and DU05

5.2 Wet Weather Calibration and Verification

5.2.1 Flow Survey Data Input

A Flow Survey Group (FSG) was created where two flow surveys were made: "Full period" and "BDU03 and BDU04". The former includes flow survey data (flow, depth, velocity, and rainfall) for wet weather calibration of all meters except BDU03 and BDU04. The latter is used for wet weather calibration of BDU03 and BDU04 only.

5.2.2 Calibration Parameters and Sensitivity

According to the BaSES manual, the Storm Water Management Model (SWMM) surface runoff routine was used to represent storm inflow entering the collection system. It is understood that the City has separate sewer systems; therefore SWMM surface runoff routine will be used as a surrogate RDII simulator. Those parameters in SWMM do not have physical significance and do not represent reality. The SWMM routing model and associated parameters are described below.

$$Q = W\frac{1.49}{n}\left(d - d_p\right)^{5/3} s^{1/2}$$

Where:
Q is the inflow to sewer in each step
W is catchment width in ft, defined in InfoWorks CS as sub-catchment "Dimension"
n is manning's overland roughness coefficient, defined in InfoWorks CS as "Runoff Routing Value"
d is rain depth on catchment surface
d_p is depression storage, defined in InfoWorks CS as "Initial Loss Value"
s is the catchment slope

Catchment Width

The dimension of a catchment is represented as catchment width in the SWMM routing model. By default, InfoWorks CS determines this parameter based on area and shape of a catchment. In this project, RJN has adjusted this parameter where appropriate. Catchment width is a key parameter to impact the shape of a hydrograph when tested in the model. A larger width will increase the flow rate and shorten the peaking time.

Manning's Overland Roughness

Manning's overland roughness (n) is another factor that can greatly impact the shape of a hydrograph. While this parameter has no physical meaning due to the reason mentioned above, an initial guess of this parameter based on the surface (i.e., road, roof, or lawn) yields reasonable response. In this project, roughness values 0.013 to 0.020 were assigned to road and roof, and roughness values 0.15 to 0.20 were assigned to pervious areas. Larger n values (e.g., 0.15 vs. 0.015) will contribute to attenuated peak flow and delayed peaking time.

Depression Storage

Depression storage represents a portion of the gross rainfall that will be intercepted through surface ponding. This parameter can be important when storms are small (e.g., 0.2-inch rainfall). In this project, this parameter was determined through plotting inflow/infiltration (RDII) vs. rainfall in Sliicer. Examination of such plots for all basins indicates the depression storage generally falls within 0.1 – 0.3 inches. In this project, a depression storage value of 0.1 inches was assigned to roads and roofs, and a depression storage value of 0.2 inches was assigned to pervious areas. Details of this will be described in **Section 5.2.3**.

Catchment Slope

By default, catchment slope is determined in InfoWorks CS from ground level elevations of manholes inside a catchment. It is not a sensitive parameter and required minimal adjustments.

Fixed Runoff Coefficient

The fixed runoff coefficient (R), also known as capture coefficient, represents the fraction of rainfall getting into the collection system. It is the most important parameter impacting not only the amount of inflow/infiltration (i.e., volume), but also the shape of a hydrograph (peak rate and peaking time). A greater R value will produce larger inflow/infiltration, increase peak flow, and reduce peaking time (minor impact). This parameter was determined through plotting inflow/infiltration (RDII) vs. rainfall in Sliicer and is described in additional detail below in **Section 5.2.3**.

5.2.3 Sliicer Application (Wet Weather Analysis)

Rainfall data from the 20 rain gauges and Doppler radar were loaded into Sliicer by ADS. Sliicer creates weighted rain gauge rainfall based on the distance from the centroid of a meter basin to each of the rain gauges. Integrated rainfall intensity data (rain gauge-adjusted radar rainfall data) were then generated for each meter basin. Such rainfall data were imported into InfoWorks CS and placed under "Flow Survey Group" or under "Rainfall Group". Sub-catchments within a meter basin have the same rain profile. The rainfall profile ID for each meter basin is presented in **Table 2**.

Once average dry weather diurnal curves (weekday and weekend) have been determined for each meter basin, they were subtracted from the wet weather meter flow in Sliicer to determine rainfall dependent inflow and infiltration (RDII). Sliicer then plots RDII volume (in million gallons, MG) vs. rainfall (in inches, in) and an example is shown in

Figure 5-1 for basin BDU01. Each data point in this plot denotes a storm event and the regression line intercepts with the rainfall axis. The intercept (0.25 inches) represents depression storage prior to surface runoff. The slope of the regression line represents the amount of inflow/infiltration per inch of rainfall, and it can be used to calculate the capture coefficient, or fixed runoff coefficient (R) in InfoWorks CS terminology using the equation below:

$$R = 36.83 \times \frac{S}{A}$$

Where:
36.83 is a unit conversion factor
S is the slope of the regression line in MG/in
A is the meter basin area in acre

BDU01 covers an area of 145 acres and the calculated R value (0.11) suggests that 11% of rain falling on BDU01 will enter the Dundalk collection system as inflow/infiltration.

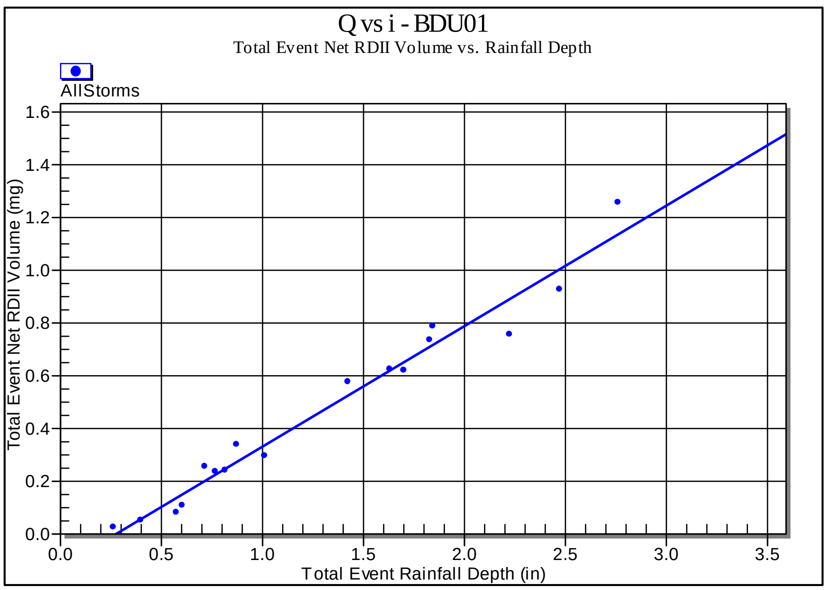

Figure 5-1: Q vs. I plots for BDU01 Basin

5.2.4 Outfall Boundary Condition

To accurately reflect the hydraulics at the outfall of the Dundalk sewershed into the Outfall interceptor, the level condition has been included in the model. The Outfall interceptor at the confluence with the Dundalk sewershed is a 147-by-132 inch pipe with a slope of 0.023%. There is approximately 34.3 inches of silt in the interceptor according to the site report. Just downstream of the confluence, a meter TSOUT02 was installed to monitor the combined flow. Given all the information above, a simple hydraulic model was built with two inflow events (i.e., TSDU03 flow and incoming flow from the Outfall sewershed to the confluence) and one level event at TSOUT02. The water depths predicted at the confluence were then used to create a level event at the outfall of the Dundalk model. This level event was not applied while dry weather calibration was performed because a free outfall scenario was observed (a 6.5-foot drop exists at the outfall to the Outfall interceptor). It is noted that significant sewer surcharge occurred under large storm events (e.g., November 16 2006 storm event) and caused backwater condition at the outfall of the Dundalk. This level event was applied while the Dundalk hydraulic model was calibrated to all 29 storm events.

5.2.5 Calibration Procedures

Below is the procedure used to run a wet weather calibration of the Dundalk sewershed model.

1. From the “Routing Model” drop down list, select “SWMM” and from the “Runoff Volume Type” drop down list select “Fixed”
2. Select Initial Loss Type” as “absolute” and input “Initial Loss Values” for three surfaces: road (0.0083 ft), roof (0.0083 ft), and pervious area (0.0167 ft).
3. Specify the “Fixed Runoff Coefficients” based on RDII vs. Rainfall plots
4. Specify “Runoff Routing Values” for three surfaces (initial values for roads, roofs, and pervious areas are 0.015, 0.015, and 0.15).
5. Specify catchment dimension and catchment slope (an initial simulation will be performed with default dimension and slope)
6. Run simulation and compare modeled response to observed data

In instances where volumes do not match closely, repeat step 3 until a reasonable match in volume is achieved. Repeat steps 4 to 6 to make peak flow rate and peaking time match observed data. When necessary, “Horton” or “Green Ampt” method was selected to replace the “Fixed” runoff volume type for pervious areas (These two methods allow a change in infiltration rate during a storm). Further calibration and verification with different storm events involve iterations of steps 3 to 6.

5.2.6 Calibration Criteria

Modeled and observed data were plotted in time series comparing flow, depth, and velocity for each meter site. The following criteria was used to perform the wet weather calibration:

- The modeled peak flow should be within -10% and +25% of the observed peak flow
- The modeled volume should be within -10% and +20% of the observed volume

- The modeled water depth in surcharged sewers of 21 inches or larger should be within -4 and +18 inches of corresponding observed depth; The modeled water depth in sewers less then 21 inches in diameter should be within -4 and +6 inches of the observed depth
- For unsurcharged critical structures, the modeled water depth should be within 4 inches of the observed one
- The modeled hydrograph properties, including time-to-peak and hydrograph shape, should in general match those of observed hydrographs

5.2.7 Calibration Results

As illustrated in the flow meter schematic (**Figure 1-2**), BDU03 and BDU04 are tributary basins of DU05 and meters for the two sites were installed in March 2008. Wet weather calibrations of BDU03 and BDU04 were based on two storm events on May 08 2008 and June 03 2008. It is noted that meters for BDU03 and BDU04 are located within the County boundaries and the sewer network within the County boundaries was not modeled in this project. Consequently, data from each of the two meters is assigned in the model to the City manhole on the reach nearest the Baltimore City/Baltimore County line. Peak flow and volume for BDU03 and BDU04 were still compared while no depth comparison was made. With calibrated parameters, the modeled response (**See Table 15 and Appendix B**) aligns well with observed data. The meter for BDU04 receives flow from a force main (a County pump station exists in BDU04 basin) which leads to flow spikes in the metered data.

Once parameters were optimized for BDU03 and BDU04, calibration was continued while parameters for other basins were adjusted. The calibration was initially based on two storm events in summer 2006: June 02 2006 and July 05 2006 storms. They produced 1.18 inches and 2.11 inches, respectively, of rainfall within 24 hours (DU04RG data). Subsequently, three other summer storms, two fall storms, one winter storm and one spring 2007 storm were used to further calibrate the model. Lastly, the rest of the 29 storms were simulated to verify the accuracy of the calibrated model. Note: storm events on June 24 2006 and June 25 2006 were combined into one storm event for simulation.

After the first round of model calibration and verification, metered vs. modeled results were reviewed. It was found that the Dundalk Sewershed exhibits higher inflow and infiltration (a larger capture coefficient, R-value) in winter than compared to summer. This is particularly appreciable for basins DU01, DU07, and BDU01. Such a behavior is not unexpected because the ground is wetter and the groundwater table is higher in winter than in summer. This leads to more inflow/infiltration per same amount of rainfall in winter than in summer. Despite different responses of the Dundalk Sewershed to winter and summer storms, a median R value was tuned and used in the model as a compromise. The modeled and observed data are summarized in **Tables 6 thru 14 and Table 16** and time series plots of flow, depth, and velocity are provided in **Appendix B**. By using a median R-value, the model tends to over-predicts summer storms and under-predict winter storms. Nevertheless, statistical plots of modeled response (peak flow and volume) versus observed data (**Appendix C)** illustrates that the model behaves in a realistic fashion and overall the model is not biased (a slope and an intercept of the regression line close to 1 and 0, respectively). In addition, executing the model with a median R-value serves to provide a conservative analysis of system capacity under design storm events since the design storms, behaving like summer storms, are short and intense.

Table 6
Dundalk Model Calibration Report: Model Calibration and Verification
DU01 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	Difference	Obs	Sim	Error%	
05/11/2006	60	2.404	2.302	-1.2	2.962	4.750	60.4%	30 minutes	2.994	3.267	9.1%	
05/14/2006	25	1.416	1.215	-2.4	2.071	1.404	-32.2%	30 minutes	1.203	0.976	-18.9%	
06/02/2006	36	1.236	1.741	6.1	3.481	3.236	-7.0%	30 minutes	1.663	1.703	2.4%	
06/19/2006	34	0.653	1.191	6.5	1.335	1.352	1.3%	30 minutes	1.021	1.259	23.3%	
06/24/2006	155	4.346	N/A	N/A	4.916	N/A	N/A	N/A	7.808	N/A	N/A	Anomalous rainfall data (19:00 – 21:00 on June 27 2006)
07/05/2006	61	1.997	2.405	4.9	4.437	5.619	26.6%	N/A	2.573	3.662	42.3%	Anomalous flow data during peak rain (flow and depth drop to zero)
07/22/2006	58	1.112	1.794	8.2	1.868	3.311	77.2%	1 hour	2.020	2.826	39.9%	
09/01/2006	66	1.742	1.803	0.7	3.436	3.369	-1.9%	1 hour	3.849	4.311	12.0%	
09/05/2006	70	1.951	2.238	3.4	5.240	5.233	-0.1%	Match	3.854	3.990	3.5%	
09/14/2006	71	1.839	1.595	-2.9	3.365	2.563	-23.8%	30 minutes	3.822	4.183	9.4%	
09/28/2006	31	1.197	1.427	2.8	2.279	2.035	-10.7%	30 minutes	1.453	1.553	6.9%	
10/05/2006	76	1.521	1.525	0.0	3.927	2.332	-40.6%	1 hour	3.815	4.085	7.1%	Peak flow (spike) observed suspect
10/17/2006	41	1.639	1.420	-2.6	2.805	1.992	-29.0%	Match	2.157	1.972	-8.6%	
10/19/2006	28	1.275	1.269	-0.1	2.202	1.558	-29.2%	Match	1.593	1.301	-18.3%	
10/27/2006	60	2.204	1.957	-3.0	5.097	3.982	-21.9%	Match	3.843	3.566	-7.2%	

Table 6 (Continued)
Dundalk Model Calibration Report: Model Calibration and Verification
DU01 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	Difference	Obs	Sim	Error%	
11/07/2006	54	1.855	1.64	-2.6	3.332	2.766	-17.0%	Match	2.655	2.965	11.7%	
11/16/2006	40	3.480	2.999	-5.8	6.895	7.800	13.1%	Match	2.661	3.492	31.2%	
11/22/2006	62	1.429	1.274	-1.9	2.401	1.578	-34.3%	Match	2.966	2.770	-6.6%	
12/22/2006	60	1.196	1.339	1.7	2.621	1.745	-33.4%	2 hours	2.842	2.641	-7.1%	
12/25/2006	36	1.204	1.272	0.8	1.875	1.574	-16.1%	Match	1.792	1.676	-6.5%	
12/31/2006	51	1.425	1.559	1.6	3.168	2.446	-22.8%	Match	2.205	2.580	17.0%	
01/07/2007	55	1.601	1.356	-2.9	2.268	1.780	-21.5%	Match	2.675	2.564	-4.1%	
03/01/2007	54	1.444	1.391	-0.6	2.617	1.862	-28.8%	Match	2.867	2.359	-17.7%	
03/15/2007	80	2.177	1.772	-4.9	4.791	3.191	-33.4%	Match	6.041	4.790	-20.7%	
03/23/2007	59	1.183	1.126	-0.7	1.477	1.151	-22.1%	Match	2.625	1.997	-23.9%	
04/04/2007	45	1.375	1.305	-0.8	2.193	1.659	-24.4%	Match	2.183	1.853	-15.1%	
04/11/2007	51	1.894	1.173	-8.7	2.457	1.267	-48.4%	1 hour	2.508	2.076	-17.2%	
04/14/2007	77	2.441	1.927	-6.2	4.603	3.833	-16.7%	Match	6.097	5.127	-15.9%	

* Error in depth is expressed in inches.

Table 7
Dundalk Model Calibration Report: Model Calibration and Verification
DU02 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
05/11/2006	60	0.783	0.721	-0.7	1.419	2.933	106.7%	Match	2.044	2.023	-1.0%	
05/14/2006	25	0.693	0.478	-2.6	1.065	1.169	9.8%	Match	0.917	0.809	-11.8%	
06/02/2006	36	0.881	0.699	-2.2	2.314	2.745	18.6%	Match	1.241	1.276	2.8%	
06/19/2006	34	0.674	0.503	-2.1	0.988	1.315	33.1%	Match	1.074	1.068	-0.6%	
06/24/2006	155	1.062	N/A	N/A	3.392	N/A	N/A	N/A	5.810	N/A	N/A	Anomalous rainfall data (19:00 – 21:00 on June 27 2006)
07/05/2006	61	0.972	0.719	-3.0	2.688	2.914	8.4%	Match	2.078	2.128	2.4%	
07/22/2006	58	0.668	0.595	-0.9	1.122	1.931	72.1%	30 minutes	1.697	1.845	8.7%	
09/01/2006	66	0.828	0.527	-3.6	1.848	1.466	-20.7%	Match	2.410	2.353	-2.4%	
09/05/2006	70	0.991	0.692	-3.6	2.861	2.686	-6.1%	Match	2.414	2.396	-0.7%	
09/14/2006	71	0.801	0.533	-3.2	1.655	1.508	-8.9%	30 minutes	2.404	2.454	2.1%	
09/28/2006	31	0.727	0.571	-1.9	1.226	1.765	43.9%	Match	1.002	1.052	5.0%	Peak flow observed less than that at upstream basin (DU03)
10/05/2006	76	0.735	0.488	-3.0	1.296	1.224	-5.6%	Match	2.670	2.508	-6.1%	
10/17/2007	41	0.719	0.500	-2.6	1.242	1.301	4.8%	Match	1.420	1.383	-2.6%	
10/19/2006	28	0.680	0.449	-2.8	1.097	1.001	-8.8%	Match	0.985	0.929	-5.7%	
10/27/2006	60	0.953	0.580	-4.5	2.929	1.827	-37.6%	1 hour	2.340	2.068	-11.6%	

Table 7 (Continued)
Dundalk Model Calibration Report: Model Calibration and Verification
DU02 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
11/07/2006	54	0.798	0.541	-3.1	1.882	1.557	-17.3%	Match	2.003	1.876	-6.3%	
11/16/2006	40	1.188	0.866	-3.9	4.028	4.308	6.9%	Match	1.680	1.697	1.0%	
11/22/2006	62	0.845	0.462	-4.6	1.875	1.077	-42.6%	Match	1.839	2.065	12.3%	Flow data missing and velocity drops to zero after rain
12/22/2006	60	0.733	0.461	-3.3	1.440	1.073	-25.5%	2 hours	2.031	1.946	-4.2%	
12/25/2006	36	0.654	0.482	-2.1	1.096	1.188	8.4%	Match	1.246	1.235	-0.9%	
12/31/2006	51	0.783	0.529	-3.0	1.555	1.480	-4.8%	Match	1.854	1.778	-4.1%	
01/07/2007	55	0.720	0.469	-3.0	1.255	1.118	-10.9%	Match	1.911	1.892	-1.0%	
03/01/2007	54	0.817	0.461	-4.3	1.722	1.072	-37.7%	Match	2.036	1.640	-19.4%	
03/15/2007	80	0.804	0.528	-3.3	1.429	1.478	3.4%	30 minutes	2.027	2.661	31.3%	
03/23/2007	59	0.578	0.428	-1.8	0.589	0.889	50.9%	Match	1.133	1.679	48.2%	Peak flow and volume observed less than those at upstream basin (DU03)
04/04/2007**	45	N/A	0.470	N/A	1.077	1.124	4.3%	30 minutes	1.336	1.367	2.3%	
04/11/2007**	51	N/A	0.421	N/A	1.157	0.854	-26.2%	1 hour	1.534	1.534	0.0%	
04/14/2007**	77	N/A	0.542	N/A	N/A	1.567	N/A	N/A	N/A	2.648	N/A	Flow data missing during rain

* Error in depth is expressed in inches.
** Depth and velocity data are not available after 04/01/2007; no depth comparison was made for any storm after 04/01/2007.

Table 8
Dundalk Model Calibration Report: Model Calibration and Verification
DU03 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
05/11/2006	60	0.319	0.630	3.7	0.867	2.401	176.8%	Match	1.665	1.717	3.1%	
05/14/2006	25	0.315	0.406	1.1	0.705	0.955	35.5%	30 minutes	0.656	0.691	5.3%	
06/02/2006	36	0.529	0.632	1.2	1.944	2.419	24.4%	Match	1.100	1.095	-0.5%	
06/19/2006	34	0.370	0.424	0.6	1.065	1.069	0.4%	Match	0.905	0.910	0.6%	
06/24/2006	155	0.603	N/A	N/A	2.595	N/A	N/A	N/A	5.269	N/A	N/A	Anomalous rainfall data (19:00 – 21:00 on June 27 2006)
07/05/2006	61	0.546	0.616	0.8	2.341	2.289	-2.2%	Match	1.782	1.791	0.5%	
07/22/2006	58	0.385	0.485	1.2	1.084	1.423	31.3%	Match	1.512	1.573	4.0%	
09/01/2006	66	0.477	0.434	-0.5	1.677	1.144	-31.8%	Match	2.284	1.992	-12.8%	
09/05/2006	70	0.550	0.597	0.6	2.268	2.167	-4.5%	Match	2.250	2.036	-9.5%	
09/14/2006	71	0.467	0.446	-0.3	1.664	1.215	-27.0%	30 minutes	2.425	2.085	-14.0%	Peak flow and volume observed greater than those at downstream basin (DU02)
09/28/2006	31	0.406	0.462	0.7	1.329	1.306	-1.8%	Match	0.952	0.883	-7.2%	
10/05/2006	76	0.393	0.414	0.3	1.226	1.005	-18.0%	Match	2.414	2.136	-11.5%	
10/17/2006	41	0.351	0.426	0.9	0.898	1.084	20.7%	Match	1.260	1.172	-7.0%	
10/19/2006	28	0.386	0.391	0.1	1.022	0.879	-14.0%	Match	0.888	0.782	-11.9%	
10/27/2006	60	0.499	0.507	0.1	1.494	1.547	3.5%	30 minutes	2.038	1.752	-14.0%	

Table 8 (Continued)
Dundalk Model Calibration Report: Model Calibration and Verification
DU03 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
11/07/2006	54	0.451	0.457	0.1	1.450	1.278	-11.9%	Match	1.669	1.655	-0.8%	
11/16/2006	40	0.646	0.772	1.5	2.967	3.567	20.2%	Match	1.421	1.460	2.7%	
11/22/2006	62	0.403	0.399	0.0	1.165	0.918	-21.2%	Match	1.918	1.843	-3.9%	
12/22/2006	60	0.431	0.396	-0.4	1.215	0.904	-25.6%	2 hours	1.845	1.744	-5.5%	
12/25/2006	36	0.419	0.417	0.0	1.021	1.022	0.1%	Match	1.149	1.095	-4.7%	
12/31/2006	51	0.435	0.454	0.2	1.349	1.262	-6.4%	Match	1.659	1.586	-4.4%	
01/07/2007	55	0.376	0.412	0.4	1.077	0.989	-8.2%	Match	1.784	1.696	-4.9%	
03/01/2007	54	0.410	0.402	-0.1	1.215	0.933	-23.2%	Match	1.715	1.388	-19.1%	
03/15/2006	80	0.542	0.446	-1.2	1.812	1.214	-33.0%	30 minutes	3.118	2.236	-28.3%	Peak flow and volume observed greater than those at downstream basin (DU02)
03/23/2007	59	0.360	0.367	0.1	0.794	0.772	-2.8%	Match	1.559	1.440	-7.6%	
04/04/2007**	45	N/A	0.400	N/A	1.074	0.925	-13.9%	Match	1.152	1.168	1.4%	
04/11/2007**	51	N/A	0.366	N/A	1.061	0.767	-27.7%	Match	1.407	1.296	-7.9%	
04/14/2007**	77	N/A	0.458	N/A	N/A	1.285	N/A	N/A	N/A	2.216	N/A	Flow data missing during rain

* Error in depth is expressed in inches.
** Depth and velocity data are not available after 04/01/2007; no depth comparison was made for any storm after 04/01/2007.

Table 9
Dundalk Model Calibration Report: Model Calibration and Verification
DU04 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
05/11/2006**	60	N/A	0.534	N/A	0.478	1.062	122.2%	30 minutes	0.367	0.434	18.3%	
05/14/2006**	25	N/A	0.284	N/A	0.229	0.262	14.4%	30 minutes	0.170	0.161	-5.3%	
06/02/2006**	36	N/A	0.338	N/A	0.459	0.397	-13.5%	1 hour	0.190	0.223	17.4%	
06/19/2006**	34	N/A	0.274	N/A	0.273	0.240	-12.1%	Match	0.290	0.203	-30.0%	
06/24/2006**	155	N/A	N/A	N/A	0.837	N/A	N/A	N/A	1.455	N/A	N/A	Anomalous rainfall data (19:00 – 21:00 on June 27 2006)
07/05/2006**	61	N/A	0.546	N/A	0.561	1.112	98.2%	Match	0.535	0.509	-4.9%	
07/22/2006**	58	N/A	0.452	N/A	0.376	0.748	98.9%	1 hour	N/A	0.399	N/A	Flow shifts after dropping to zero
09/01/2006**	66	N/A	0.397	N/A	0.488	0.566	16.0%	30 minutes	0.711	0.830	16.7%	
09/05/2006**	70	N/A	0.518	N/A	N/A	0.998	N/A	N/A	0.867	0.885	2.1%	Flow drops to zero during rain
09/14/2006**	71	N/A	0.384	N/A	0.516	0.528	2.3%	Match	0.979	0.886	-9.5%	
09/28/2006**	31	N/A	0.393	N/A	0.471	0.554	17.6%	Match	0.355	0.384	8.2%	
10/05/2006**	76	N/A	0.369	N/A	0.380	0.482	26.8%	Match	0.709	0.878	23.8%	
10/17/2006**	41	N/A	0.369	N/A	0.404	0.484	19.8%	1 hour	0.502	0.503	0.2%	
10/19/2006**	28	N/A	0.342	N/A	0.402	0.408	1.5%	Match	0.344	0.338	-1.7%	
10/27/2006**	60	N/A	0.454	N/A	N/A	0.756	N/A	N/A	0.741	0.724	-2.3%	Flow drops to zero during rain

Table 9 (Continued)
Dundalk Model Calibration Report: Model Calibration and Verification
DU04 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
11/07/2006	54	0.561	0.428	-1.6	N/A	0.666	N/A	N/A	N/A	0.797	N/A	Flow drops to zero during and after rain
11/16/2006	40	0.881	0.689	-2.3	N/A	1.790	N/A	N/A	N/A	0.698	N/A	Flow and velocity drop to zero
11/22/2006	62	0.541	0.362	-2.1	N/A	0.463	N/A	N/A	0.949	0.864	-9.0%	Flat flow during rain and velocity drops to zero
12/22/2006	60	0.499	0.361	-1.7	0.480	0.460	-4.2%	2 hours	0.735	0.777	5.7%	
12/25/2006	36	0.470	0.370	-1.2	0.410	0.486	18.5%	Match	0.530	0.516	-2.6%	
12/31/2006	51	0.518	0.420	-1.2	0.474	0.640	35.0%	Match	0.760	0.728	-4.2%	
01/07/2007	55	0.504	0.356	-1.8	0.475	0.444	-6.5%	Match	0.899	0.763	-15.1%	
03/01/2007	54	0.529	0.396	-1.6	0.598	0.564	-5.7%	Match	0.869	0.835	-3.9%	
03/15/2007	80	0.620	0.433	-2.2	0.724	0.685	-5.4%	Match	1.441	1.316	-8.7%	
03/23/2007	59	0.483	0.346	-1.6	0.479	0.419	-12.5%	1 hour	0.824	0.842	2.2%	
04/04/2007**	45	N/A	0.388	N/A	0.541	0.540	-0.2%	Match	0.830	0.730	-12.0%	
04/11/2007**	51	N/A	0.366	N/A	0.629	0.475	-24.5%	Match	0.933	0.807	-13.5%	
04/14/2007**	77	N/A	0.449	N/A	N/A	0.739	N/A	N/A	N/A	1.329	N/A	Flow drops to zero during and after rain

* Error in depth is expressed in inches.
** Depth and velocity data are not available from 05/09/2006 to 11/02/2006 and after 04/01/2007; no depth comparison was made for storms during these periods.

Table 10
Dundalk Model Calibration Report: Model Calibration and Verification
DU05 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
05/11/2006	60	1.866	2.267	4.8	8.913	13.802	54.8%	30 minutes	9.728	10.883	11.9%	
05/14/2006	25	1.193	1.207	0.2	4.911	5.046	2.7%	Match	3.934	4.105	4.3%	
06/02/2006	36	1.651	1.547	-1.3	7.673	7.869	2.5%	1 hour	6.196	6.234	0.6%	
06/19/2006	34	1.112	1.124	0.1	4.037	4.448	10.2%	1 hour	4.865	5.366	10.3%	
06/24/2006	155	9.499	N/A	N/A	16.803	N/A	N/A	N/A	35.232	N/A	N/A	Anomalous rainfall data (19:00 – 21:00 on June 27 2006)
07/05/2006	61	4.106	2.202	-22.8	19.348	13.291	-31.3%	1.5 hour	12.574	11.166	-11.2%	
07/22/2006	58	1.399	1.676	3.3	5.929	8.910	50.3%	30 minutes	9.081	9.842	8.4%	
09/01/2006	66	1.660	1.560	-1.2	8.115	7.954	-2.0%	1 hour	12.892	12.904	0.1%	
09/05/2006	70	3.436	1.975	-17.5	10.989	11.492	4.6%	1 hour	13.967	12.390	-11.3%	
09/14/2006	71	1.701	1.427	-3.3	8.707	6.801	-21.9%	1 hour	14.633	13.155	-10.1%	
09/28/2006	31	1.250	1.433	2.2	5.554	6.804	22.5%	1 hour	4.956	5.518	11.3%	
10/05/2006	76	1.405	1.407	0.0	6.350	6.623	4.3%	Match	13.231	13.705	3.6%	
10/17/2006	41	1.255	1.303	0.6	5.453	5.838	7.1%	Match	6.528	7.254	11.1%	
10/19/2006	28	1.320	1.229	-1.1	5.688	5.191	-8.7%	1 hour	5.028	5.067	0.8%	
10/27/2006	60	2.589	1.651	-11.3	9.482	8.654	-8.7%	1.5 hour	12.510	11.334	-9.4%	

Table 10 (Continued)
Dundalk Model Calibration Report: Model Calibration and Verification
DU05 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
11/07/2006	54	1.927	1.444	-5.8	8.649	6.929	-19.9%	30 minutes	11.284	10.136	-10.2%	
11/16/2006	40	7.079	3.056	-48.3	14.767	17.207	16.5%	Match	9.354	8.940	-4.4%	Flow and velocity drop to zero
11/22/2006	62	1.513	1.271	-2.9	7.078	5.573	-21.3%	Match	12.902	10.821	-16.1%	
12/22/2006	60	1.389	1.322	-0.8	6.289	5.993	-4.7%	2 hours	10.613	10.485	-1.2%	
12/25/2006	36	1.299	1.279	-0.2	5.784	5.640	-2.5%	Match	7.006	6.560	-6.4%	
12/31/2006	51	1.585	1.566	-0.2	7.598	8.000	5.3%	1 hour	10.142	9.961	-1.8%	
01/07/2007	55	1.476	1.338	-1.7	6.873	6.127	-10.9%	Match	11.164	10.535	-5.6%	
03/01/2007	54	1.472	1.295	-2.1	6.743	5.780	-14.3%	Match	10.215	9.657	-5.5%	
03/15/2007	80	3.659	1.560	-25.2	11.445	7.977	-30.3%	1.5 hour	19.514	15.827	-18.9%	
03/23/2007	59	1.237	1.243	0.1	5.102	5.299	3.9%	Match	9.779	9.951	1.8%	
04/04/2007**	45	N/A	1.385	N/A	5.858	6.455	10.2%	30 minutes	7.502	7.931	5.7%	
04/11/2007**	51	N/A	1.219	N/A	7.398	5.109	-30.9%	30 minutes	9.294	8.929	-3.9%	
04/14/2007**	77	N/A	1.688	N/A	13.842	9.027	-34.8%	1 hour	19.846	15.635	-21.2%	Flow data missing after rain

* Error in depth is expressed in inches.
** Depth and velocity data are not available after 04/01/2007; no depth comparison was made for any storm after 04/01/2007.

Table 11
Dundalk Model Calibration Report: Model Calibration and Verification
DU06 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
05/11/2006	60	1.253	1.846	7.1	3.394	8.254	143.2%	1 hour	3.267	4.138	26.7%	
05/14/2006	25	0.970	0.790	-2.2	1.912	2.460	28.6%	1 hour	1.329	1.508	13.5%	
06/02/2006	36	1.419	1.120	-3.6	4.512	4.578	1.5%	1 hour	2.480	2.393	-3.5%	
06/19/2006	34	0.872	0.735	-1.7	1.573	1.990	26.4%	30 minutes	1.726	1.838	6.5%	
06/24/2006	155	12.779	N/A	N/A	14.293	N/A	N/A	N/A	15.845	N/A	N/A	Anomalous rainfall (19:00 – 21:00 on June 27 2006)
07/05/2006	61	2.355	1.873	-5.8	7.277	8.350	14.7%	1 hour	5.011	4.250	-15.2%	
07/22/2006	58	1.042	1.236	2.3	2.067	5.225	152.8%	1.5 hour	3.215	3.574	11.2%	
09/01/2006	66	1.207	1.042	-2.0	3.496	4.045	15.7%	1 hour	4.956	5.209	5.1%	
09/05/2006	70	1.752	1.510	-2.9	5.493	6.899	25.6%	1 hour	4.977	4.719	-5.2%	
09/14/2006	71	1.234	0.938	-3.6	3.698	3.354	-9.4%	1 hour	5.434	5.161	-5.0%	
09/28/2006	31	1.031	0.980	-0.6	2.604	3.678	41.3%	1 hour	2.001	2.068	3.3%	
10/05/2006	76	1.101	0.895	-2.5	3.108	3.097	-0.4%	Match	6.123	5.338	-12.8%	
10/17/2006	41	1.061	0.842	-2.6	2.800	2.800	0.0%	Match	2.715	2.751	1.3%	
10/19/2006	28	1.071	0.785	-3.4	2.642	2.439	-7.7%	Match	2.032	1.941	-4.5%	
10/27/2006	60	1.871	1.228	-7.7	5.926	5.269	-11.1%	1 hour	5.356	4.554	-15.0%	

Table 11 (Continued)
Dundalk Model Calibration Report: Model Calibration and Verification
DU06 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
11/07/2006	54	1.458	1.058	-4.8	4.332	4.157	-4.1%	Match	4.969	4.097	-17.5%	
11/16/2006	40	8.833	4.991	-46.1	14.377	11.656	-18.9%	Match	4.516	3.991	-11.6%	
11/22/2006	62	1.242	0.798	-5.3	3.453	2.505	-27.4%	Match	5.436	4.150	-23.7%	
12/22/2006	60	1.180	0.824	-4.3	3.115	2.694	-13.5%	2 hours	4.470	4.024	-10.0%	
12/25/2006	36	1.057	0.825	-2.8	2.689	2.700	0.4%	Match	3.015	2.585	-14.3%	
12/31/2006	51	2.534	1.085	-17.4	7.837	4.324	-44.8%	1 hour	4.732	4.433	-6.3%	Peak flow (spike) observed suspect
01/07/2007	55	1.140	0.853	-3.4	3.036	2.879	-5.1%	Match	4.512	4.664	3.4%	
03/01/2007	54	1.249	0.813	-5.2	3.796	2.652	-30.1%	30 minutes	4.477	3.877	-13.4%	
03/15/2007	80	1.800	1.040	-9.1	6.069	4.048	-33.3%	30 minutes	9.179	6.746	-26.5%	
03/23/2007	59	1.003	0.752	-3.0	2.618	2.125	-18.8%	Match	4.388	3.838	-12.5%	
04/04/2007**	45	N/A	0.869	N/A	2.886	2.957	2.5%	30 minutes	3.103	3.141	1.3%	
04/11/2007**	51	N/A	0.747	N/A	3.255	2.092	-35.7%	1 hour	3.621	3.533	-2.4%	
04/14/2007**	77	N/A	1.116	N/A	6.993	4.567	-34.7%	1 hour	8.816	6.783	-23.1%	

* Error in depth is expressed in inches.

** Depth meter data is not available after 04/01/2007; no depth comparison was made for any storm during this period.

Table 12
Dundalk Model Calibration Report: Model Calibration and Verification
DU07 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
05/11/2006	60	0.424	0.917	5.9	1.501	3.971	164.6%	30 minutes	1.389	1.692	21.9%	
05/14/2006	25	0.341	0.465	1.5	0.971	1.086	11.8%	30 minutes	0.568	0.628	10.6%	
06/02/2006	36	0.533	0.641	1.3	2.345	2.046	-12.8%	1 hour	1.033	0.982	-5.8%	
06/19/2006	34	0.429	0.432	0.0	0.662	0.924	39.6%	30 minutes	0.610	0.761	24.8%	
06/24/2006	155	7.642	N/A	N/A	3.939	N/A	N/A	N/A	5.342	N/A	N/A	Anomalous rainfall data (19:00 – 21:00 on June 27 2006)
07/05/2006	61	0.581	0.929	4.2	2.571	4.075	58.5%	30 minutes	1.361	1.717	26.2%	
07/22/2006	58	0.399	0.690	3.5	1.040	2.341	125.1%	1 hour	1.109	1.414	27.5%	
09/01/2006	66	N/A	0.596	N/A	N/A	1.818	N/A	N/A	N/A	2.155	N/A	Meter data missing during rain
09/05/2006	70	0.629	0.818	2.3	2.852	3.236	13.5%	30 minutes	1.813	1.964	8.3%	
09/14/2006	71	0.475	0.539	0.8	1.742	1.436	-17.6%	1 hour	1.970	2.130	8.1%	
09/28/2006	31	0.449	0.580	1.6	1.262	1.700	34.7%	30 minutes	0.755	0.867	14.8%	
10/05/2006	76	0.451	0.524	0.9	1.371	1.365	-0.4%	Match	2.373	2.099	-11.5%	
10/17/2006	41	0.479	0.497	0.2	1.374	1.225	-10.8%	Match	1.271	1.092	-14.1%	
10/19/2006	28	0.506	0.457	-0.6	1.357	1.060	-22.0%	Match	0.984	0.764	-22.4%	
10/27/2006	60	0.637	0.717	1.0	2.941	2.579	-12.3%	1 hour	2.332	1.817	-22.1%	

Table 12 (Continued)
Dundalk Model Calibration Report: Model Calibration and Verification
DU07 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
11/07/2006	54	0.502	0.599	1.2	1.998	1.833	-8.4%	Match	2.203	1.570	-28.7%	
11/16/2006	40	3.647	1.234	-29.0	4.392	6.266	42.7%	1 hour	1.920	1.606	-16.3%	
11/22/2006	62	0.515	0.453	-0.7	1.967	1.026	-47.8%	1 hour	2.306	1.571	-31.9%	
12/22/2006	60	0.544	0.473	-0.9	1.811	1.119	-38.3%	2 hours	1.877	1.516	-19.2%	
12/25/2006	36	0.560	0.477	-1.0	1.405	1.138	-19.0%	30 minutes	1.244	0.991	-20.3%	
12/31/2006	51	0.528	0.623	1.1	2.123	1.979	-6.8%	Match	1.797	1.932	7.5%	
01/07/2007	55	0.468	0.510	0.5	1.617	1.300	-19.5%	1 hour	2.070	2.048	-1.1%	
03/01/2007	54	N/A	0.477	N/A	N/A	1.157	N/A	N/A	N/A	1.520	N/A	Flow and depth data missing during rain
03/15/2007	80	N/A	0.597	N/A	N/A	1.826	N/A	N/A	N/A	2.675	N/A	Flow and depth data missing during rain
03/23/2007	59	N/A	0.427	N/A	N/A	0.909	N/A	N/A	N/A	1.477	N/A	Flow and depth data missing during rain
04/04/2007**	45	N/A	0.491	N/A	1.536	1.199	-21.9%	1 hour	1.529	1.231	-19.5%	
04/11/2007**	51	N/A	0.420	N/A	2.049	0.872	-57.4%	30 minutes	1.608	1.381	-14.1%	
04/14/2007**	77	N/A	0.623	N/A	3.496	1.981	-43.3%	1 hour	3.850	2.696	-30.0%	

* Error in depth is expressed in inches.
** Depth and velocity data are not available after 04/01/2007; no depth comparison was made for any storm after 04/01/2007.

Table 13
Dundalk Model Calibration Report: Model Calibration and Verification
BDU01 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
05/11/2006	60	0.448	0.800	4.2	0.716	1.312	83.2%	30 minutes	0.747	0.976	30.7%	
05/14/2006	25	0.351	0.318	-0.4	0.443	0.418	-5.6%	Match	0.319	0.333	4.4%	
06/02/2006	36	0.529	0.455	-0.9	1.086	0.847	-22.0%	Match	0.613	0.573	-6.5%	
06/19/2006	34	0.303	0.287	-0.2	0.341	0.340	-0.3%	Match	0.398	0.400	0.5%	
06/24/2006	155	8.091	N/A	N/A	1.618	N/A	N/A	N/A	3.494	N/A	N/A	Anomalous rainfall data (19:00 – 21:00 on June 27 2006)
07/05/2006	61	0.631	0.891	3.1	1.104	1.406	27.4%	30 minutes	1.153	0.994	-13.8%	
07/22/2006	58	0.400	0.453	0.6	0.538	0.839	55.9%	1.5 hour	0.700	0.841	20.1%	
09/01/2006	66	N/A	0.476	NA	N/A	0.926	N/A	N/A	N/A	1.274	N/A	Flow data missing during and after rain
09/05/2006	70	0.636	0.649	0.2	1.410	1.234	-12.5%	1.5 hour	1.389	1.086	-21.8%	
09/14/2006	71	0.495	0.416	-0.9	1.061	0.710	-33.1%	Match	1.551	1.229	-20.8%	
09/28/2006	31	0.389	0.375	-0.2	0.606	0.580	-4.3%	Match	0.548	0.461	-15.9%	
10/05/2006	76	0.431	0.429	0.0	0.717	0.754	5.2%	Match	1.441	1.444	0.2%	
10/17/2006	41	0.436	0.387	-0.6	0.613	0.617	0.7%	Match	0.701	0.713	1.7%	
10/19/2006	28	0.431	0.374	-0.7	0.587	0.576	-1.9%	1.5 hour	0.494	0.501	1.4%	
10/27/2006	60	0.646	0.590	-0.7	1.266	1.153	-8.9%	Match	1.469	1.220	-17.0%	

Table 13 (Continued)
Dundalk Model Calibration Report: Model Calibration and Verification
BDU01 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
11/07/2006	54	0.552	0.464	-1.1	1.115	0.880	-21.1%	Match	1.336	1.067	-20.1%	
11/16/2006	40	1.135	3.413	27.3	1.312	2.433	85.4%	30 minutes	N/A	1.037	N/A	Flow data missing after rain
11/22/2006	62	0.537	0.372	-2.0	1.085	0.570	-47.5%	Match	1.716	1.074	-37.4%	
12/22/2006	60	0.459	0.383	-0.9	0.789	0.603	-23.6%	2 hours	1.343	1.067	-20.6%	
12/25/2006	36	0.460	0.382	-0.9	0.813	0.602	-26.0%	Match	0.919	0.663	-27.9%	
12/31/2006	51	0.567	0.488	-0.9	1.022	0.970	-5.1%	Match	1.264	1.213	-4.0%	
01/07/2007	55	0.532	0.425	-1.3	0.902	0.742	-17.7%	Match	1.414	1.284	-9.2%	
03/01/2007	54	0.439	0.431	-0.1	0.779	0.764	-1.9%	Match	0.955	1.181	23.7%	
03/15/2007	80	0.600	0.505	-1.1	1.277	1.038	-18.7%	Match	2.339	2.039	-12.8%	
03/23/2007	59	0.414	0.394	-0.2	0.642	0.641	-0.2%	Match	1.200	1.202	0.2%	
04/04/2007**	45	N/A	0.417	N/A	0.738	0.714	-3.3%	Match	0.948	0.943	-0.5%	
04/11/2007**	51	N/A	0.392	N/A	0.995	0.634	-36.3%	1 hour	1.162	1.064	-8.4%	
04/14/2007**	77	N/A	0.637	N/A	N/A	1.257	N/A	N/A	N/A	2.039	N/A	Flow drops to zero during rain

* Error in depth is expressed in inches.
** Depth and velocity data are not available after 04/01/2007; no depth comparison was made for any storm after 04/01/2007.

Table 14
Dundalk Model Calibration Report: Model Calibration and Verification
BDU02 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
05/11/2006	60	0.385	0.353	-0.4	0.475	0.612	28.8%	Match	0.411	0.525	27.7%	
05/14/2006	25	0.310	0.232	-0.9	0.239	0.258	7.9%	Match	0.172	0.190	10.5%	
06/02/2006	36	0.391	0.247	-1.7	0.287	0.302	5.2%	Match	0.339	0.308	-9.1%	
06/19/2006	34	0.330	0.222	-1.3	0.256	0.232	-9.4%	Match	0.261	0.249	-4.6%	
06/24/2006	155	1.744	N/A	N/A	1.615	N/A	N/A	N/A	1.968	N/A	N/A	Anomalous rainfall data (19:00 – 21:00 on June 27 2006)
07/05/2006	61	0.390	0.340	-0.6	0.486	0.567	16.7%	1 hour	0.595	0.526	-11.6%	
07/22/2006	58	0.317	0.290	-0.3	0.278	0.414	48.9%	Match	0.418	0.466	11.5%	
09/01/2006	66	0.409	0.296	-1.4	0.516	0.434	-15.9%	Match	0.776	0.667	-14.0%	
09/05/2006	70	0.373	0.322	-0.6	0.341	0.521	52.8%	30 minutes	0.633	0.607	-4.1%	
09/14/2006	71	0.408	0.269	-1.7	0.578	0.357	-38.2%	Match	0.921	0.667	-27.6%	
09/28/2006	31	0.396	0.253	-1.7	0.427	0.318	-25.5%	Match	0.323	0.260	-19.5%	
10/05/2006	76	0.318	0.254	-0.8	0.357	0.320	-10.4%	Match	0.623	0.674	8.2%	
10/17/2006	41	0.304	0.239	-0.8	0.284	0.279	-1.8%	Match	0.308	0.339	10.1%	
10/19/2006	28	0.292	0.235	-0.7	0.258	0.267	3.5%	Match	0.214	0.229	7.0%	
10/27/2006	60	0.351	0.309	-0.5	0.434	0.482	11.1%	1.5 hour	0.591	0.571	-3.4%	

Table 14 (Continued)
Dundalk Model Calibration Report: Model Calibration and Verification
BDU02 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
11/07/2006	54	0.352	0.272	-1.0	0.376	0.365	-2.9%	Match	0.510	0.483	-5.3%	
11/16/2006	40	0.599	0.471	-1.5	0.933	0.944	1.2%	30 minutes	0.397	0.445	12.1%	
11/22/2006	62	0.372	0.237	-1.6	0.359	0.273	-24.0%	Match	0.586	0.505	-13.8%	
12/22/2006	60	0.351	0.237	-1.4	0.224	0.273	21.9%	2 hours	0.337	0.508	50.7%	
12/25/2006	36	0.336	0.240	-1.2	0.182	0.281	54.4%	Match	0.209	0.311	48.8%	
12/31/2006	51	0.324	0.276	-0.6	0.419	0.373	-11.0%	Match	0.499	0.496	-0.6%	
01/07/2007	55	0.336	0.246	-1.1	0.408	0.299	-26.7%	30 minutes	0.573	0.525	-8.4%	
03/01/2007	54	N/A	0.246	N/A	N/A	0.299	N/A	N/A	N/A	0.467	N/A	Flow data missing during rain
03/15/2007	80	N/A	0.282	N/A	N/A	0.389	N/A	N/A	N/A	0.802	N/A	Flow and depth drop to zero during rain
03/23/2007	59	0.229	0.239	0.1	0.155	0.278	79.4%	Match	0.222	0.483	117.6%	
04/04/2007**	45	N/A	0.238	N/A	N/A	0.276	N/A	N/A	N/A	0.376	N/A	Flow data missing during and after rain
04/11/2007**	51	N/A	0.232	N/A	N/A	0.256	N/A	N/A	N/A	0.413	N/A	Flow data missing during and after rain
04/14/2007**	77	N/A	0.309	N/A	N/A	0.484	N/A	N/A	N/A	0.792	N/A	Flow data missing during and after rain

* Error in depth is expressed in inches.
** Depth and velocity data are not available after 04/01/2007; no comparison was made for any storm after 04/01/2007.

Table 15
Dundalk Model Calibration Report: Model Calibration and Verification
BDU03 and BDU04 Wet Weather Flow Calibration Statistics

	Storm Date	Simulation Time (hr)	Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
BDU03			Obs	Sim	Error%	difference	Obs	Sim	Error%	
	05/08/2008	62	1.702	1.684	-1.1%	30 minutes	2.741	2.499	-8.8%	
	06/03/2008	53	1.334	1.320	-1.0%	Match	2.147	2.100	-2.2%	
BDU04			Obs	Sim	Error	difference	Obs	Sim	Error	
	05/08/2008	62	2.563	2.595	1.2%	30 minutes	4.127	3.610	-12.5%	
	06/03/2008	53	1.806	1.930	6.9%	30 minutes	2.713	2.918	7.6%	

Table 16
Dundalk Model Calibration Report: Model Calibration and Verification
TSDU03 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
05/11/2006	60	N/A	1.621	N/A	N/A	20.891	N/A	N/A	N/A	15.170	N/A	No meter data
05/14/2006	25	N/A	1.042	N/A	N/A	7.593	N/A	N/A	N/A	5.409	N/A	No meter data
06/02/2006	36	3.361	2.419	-11.3	14.115	10.992	-22.1%	1 hour	10.433	8.436	-19.1%	
06/19/2006**	34	1.728	0.802	-11.1	7.240	6.523	-9.9%	30 minutes	7.163	7.080	-1.2%	
06/24/2006	155	5.725	N/A	N/A	30.170	N/A	N/A	N/A	70.513	N/A	N/A	Anomalous rainfall data (19:00 – 21:00 on June 27 2006)
07/05/2006	61	6.988	3.508	-41.8	26.118	19.222	-26.4%	Match	24.289	15.848	-34.8%	
07/22/2006**	58	2.384	1.412	-11.7	8.430	13.656	62.0%	30 minutes	10.400	13.504	29.8%	
09/01/2006	66	3.651	2.709	-11.3	11.538	11.799	2.3%	Match	16.028	18.667	16.5%	
09/05/2006	70	6.745	3.490	-39.1	14.545	17.439	19.9%	Match	16.682	17.798	6.7%	
09/14/2006	71	2.855	2.027	-9.9	9.785	10.420	6.5%	30 minutes	16.232	18.903	16.5%	
09/28/2006	31	2.816	1.961	-10.3	6.790	10.195	50.1%	30 minutes	6.181	7.699	24.6%	
10/05/2006	76	2.912	2.059	-10.2	7.795	9.472	21.5%	Match	16.368	19.371	18.3%	
10/17/2006	41	3.562	2.668	-10.7	6.932	8.918	28.6%	Match	8.938	10.074	12.7%	
10/19/2006	28	2.172	1.299	-10.5	7.180	7.382	2.8%	Match	6.126	6.963	13.7%	
10/27/2006	60	6.112	5.486	-7.5	16.528	17.258	4.4%	30 minutes	13.598	16.373	20.4%	

Table 16 (Continued)
Dundalk Model Calibration Report: Model Calibration and Verification
TSDU03 Wet Weather Flow Calibration Statistics

Storm Date	Simulation Time (hr)	Maximum Depth (ft)			Maximum Flow (MGD)			Peaking Time	Volume (MG)			Comments
		Obs	Sim	Error*	Obs	Sim	Error%	difference	Obs	Sim	Error%	
11/07/2006	54	5.296	4.786	-6.1	11.987	12.319	2.8%	Match	14.480	14.362	-0.8%	
11/16/2006	40	7.320	6.610	-8.5	23.093	28.413	23.0%	30 minutes	12.327	13.717	11.3%	
11/22/2006	62	2.924	2.123	-9.6	9.210	8.240	-10.5%	Match	14.990	14.972	-0.1%	
12/22/2006**	60	3.878	2.344	-18.4	7.000	7.972	13.9%	Match	13.511	14.318	6.0%	
12/25/2006	36	2.128	1.466	-7.9	7.018	8.152	16.2%	Match	8.557	9.072	6.0%	
12/31/2006	51	3.097	2.294	-9.6	9.622	11.236	16.8%	Match	13.106	13.722	4.7%	
01/07/2007	55	3.059	2.157	-10.8	9.757	8.619	-11.7%	Match	14.271	14.330	0.4%	
03/01/2007**	54	4.952	0.895	-48.7	10.363	8.969	-13.5%	30 minutes	14.161	13.369	-5.6%	
03/15/2007**	80	6.885	1.049	-70.0	19.080	12.688	-33.5%	2 hours	27.788	22.713	-18.3%	
03/23/2007**	59	2.027	0.824	-14.4	9.277	7.392	-20.3%	Match	15.342	13.263	-13.6%	
04/04/2007**	45	1.851	0.913	-11.3	7.273	9.421	29.5%	30 minutes	9.485	10.867	14.6%	
04/11/2007**	51	2.695	0.815	-22.6	9.960	7.183	-27.9%	30 minutes	12.536	12.282	-2.0%	
04/14/2007**	77	5.638	1.109	-54.3	24.985	14.259	-42.9%	Match	33.425	22.925	-31.4%	

* Error in depth is expressed in inches.
** No TSOUT02 meter data was available during labeled storm events and the simulated depth is based on free outfall condition (no backwater). Depth comparison for these storms is not valid.

6.0 SUMMARY

This report describes the development and calibration of the hydraulic model established for the Dundalk sewershed. Engineering tasks, such as flow monitoring, manhole inspection, GPS survey, and inflow/infiltration analysis, provided input data for hydraulic modeling. The objective of model calibration is to accurately describe flows tributary to the Dundalk sewershed, including residential and industrial wastewater, base infiltration, and rainfall dependent inflow/infiltration. With the hydraulic model calibrated, further modeling efforts will be performed to determine capacity required under 1, 2, 5, 10, 15, and 20 year, 24 hour duration storm events under baseline and Year 2025 conditions.

In summary, the calibration of the Dundalk hydraulic model was conducted in accordance with the BaSES manual. Dry weather calibration results indicate that modeled and observed peak flow and volume match well for all meter sites. Wet weather calibration results indicate, in general, reasonable matches in depth, peaking time, peak flow, and volume. Few discrepancies were observed and noted in this report, and causes of such discrepancies were analyzed and proposed.

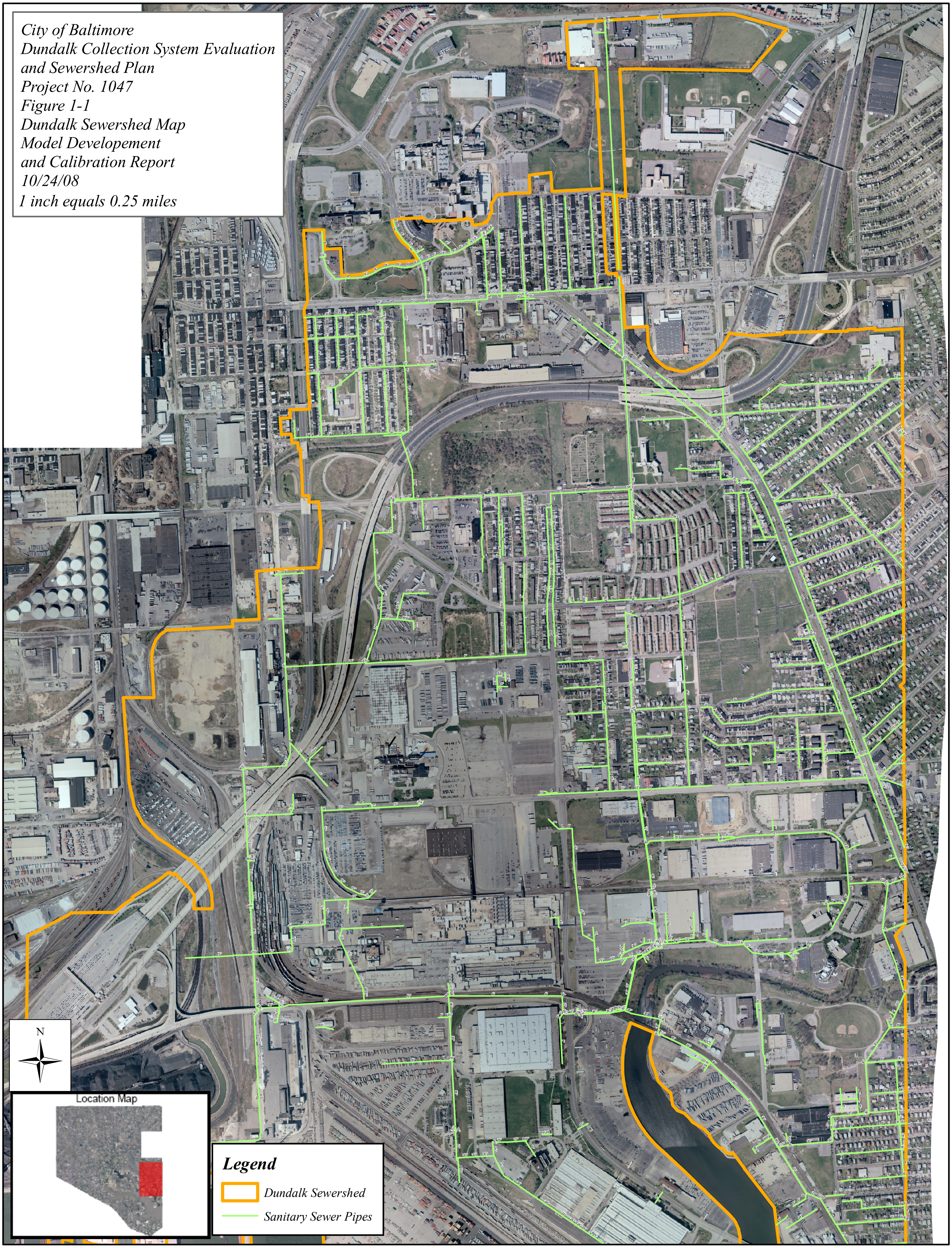
City of Baltimore
Dundalk Collection System Evaluation
and Sewershed Plan
Project No. 1047
Figure 1-1
Dundalk Sewershed Map
Model Developement
and Calibration Report
10/24/08
1 inch equals 0.25 miles
N
Location Map
Legend
Dundalk Sewershed
Sanitary Sewer Pipes

Figure 1-2: Dundalk Flow Meter Schematic